REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*

2. REPORT TYPE
Technical Paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE

5a. CONTRACT NUMBER
F04611-98-C-0003

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory (AFMC)
AFRL/PRS
5 Pollux Drive
Edwards AFB CA 93524-7048

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

20021021 068

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Leilani Richardson
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
Unclassified	Unclassified	Unclassified	A		(661) 275-5015

6 items enclosed

F04611-98-C-0003

MEMORANDUM FOR PR (Contractor/In-House Publication)

FROM: PROI (TI) (STINFO) 05 Sep 2000

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-TP-2000-175**
D. Schwartz (AFRL/PRRM), R. Bennett (Thiokol), K. Graham (ARC), T. Boggs (NAWC) , "Current Efforts to Develop Alternate Test Protocols for the Joint Technical Bulletin 'Department of Defense Ammunition and Explosives Hazard Classification Procedures' TB700-2, dated 5 January, 1998"

JANNAF PSHS **(Statement A)**
(Monterey, CA, 13-17 Nov 2000) **(Submission Deadline: 30 Oct 00)**

1. This request has been reviewed by the Foreign Disclosure Office for: a.) appropriateness of distribution statement, b.) military/national critical technology, c.) export controls or distribution restrictions, d.) appropriateness for release to a foreign nation, and e.) technical sensitivity and/or economic sensitivity.
Comments:____

Signature ____________________ Date __________

2. This request has been reviewed by the Public Affairs Office for: a.) appropriateness for public release and/or b) possible higher headquarters review.
Comments: ____

Signature ____________________ Date __________

3. This request has been reviewed by the STINFO for: a.) changes if approved as amended, b.) appropriateness of distribution statement, c.) military/national critical technology, d.) economic sensitivity, e.) parallel review completed if required, and f.) format and completion of meeting clearance form if required
Comments:____

Signature ____________________ Date __________

4. This request has been reviewed by PR for: a.) technical accuracy, b.) appropriateness for audience, c.) appropriateness of distribution statement, d.) technical sensitivity and economic sensitivity, e.) military/ national critical technology, and f.) data rights and patentability
Comments:____

APPROVED/APPROVED AS AMENDED/DISAPPROVED

____
LESLIE S. PERKINS, Ph.D (Date)
Staff Scientist
Propulsion Directorate

Current Efforts to Develop Alternate Test Protocols for the Joint Technical Bulletin "Department of Defense Ammunition and Explosives Hazard Classification Procedures" TB700-2, dated 5 January, 1998.

Daniel F. Schwartz
Air Force Research Laboratory Propulsion Directorate, Edwards AFB, CA

Dr. Robert R. Bennett
Thiokol Propulsion, Brigham City, UT

Kenneth J. Graham
Atlantic Research Corporation, Gainesville, VA

Thomas L. Boggs
Naval Air Warfare Center, China Lake, CA

ABSTRACT

When the Department of Defense (DoD) revised their Technical Bulletin (TB) 700-2, NAVSEAINST 8020.8B, TO 11A-1-47, DLAR 8220.12 hazard classification guidelines in January 1998[1], it significantly changed the procedures used to determine the explosive classification of rocket motors, to be shipped or placed in DoD storage facilities. The revised test protocols outlined in this document, (hereafter referred to as TB 700-2) were far more conservative and costly to implement than the previous ones. These changes will have a profound impact on the solid rocket community and in particular those involved with the research and development and manufacture of large rocket motors. The ramifications are higher development costs and severe limitations on performance improvements. This paper outlines the current efforts of the Air Force Research Laboratory Propulsion Directorate, Thiokol, Atlantic Research Corporation, and Naval Air Warfare Center to unite the solid rocket community into developing acceptable alternate test protocols that could fulfill the intent of TB 700-2 and be considered by the Department of Defense Explosive Safety Board (DDESB) for incorporation into a future revision to TB 700-2.

Distribution approved for public release

This material is based upon work supported by the AFRL/PRRM, Edwards AFB, CA under contracts F04611-98-C-0003 and F04611-98-C-0004.

INTRODUCTION

In May of 2000, at the Joint Army-Navy-NASA-Air Force (JANNAF) Propellant Development & Characterization Subcommittee (PDCS), Dr. Robert Bennett presented a paper titled "Comments and Position Regarding the Joint Technical Bulletin "Department of Defense Ammunition and Explosives Hazard Classification Procedures" TB700-2, dated 5 January, 1998."[2]. In the paper, he outlined the required and alternate test protocols under the revised TB 700-2; the concerns the solid rocket community had with them and made recommendations for tests that could potentially satisfy the needs of both the Department of Defense Explosive Safety Board (DDESB) and the solid rocket community.

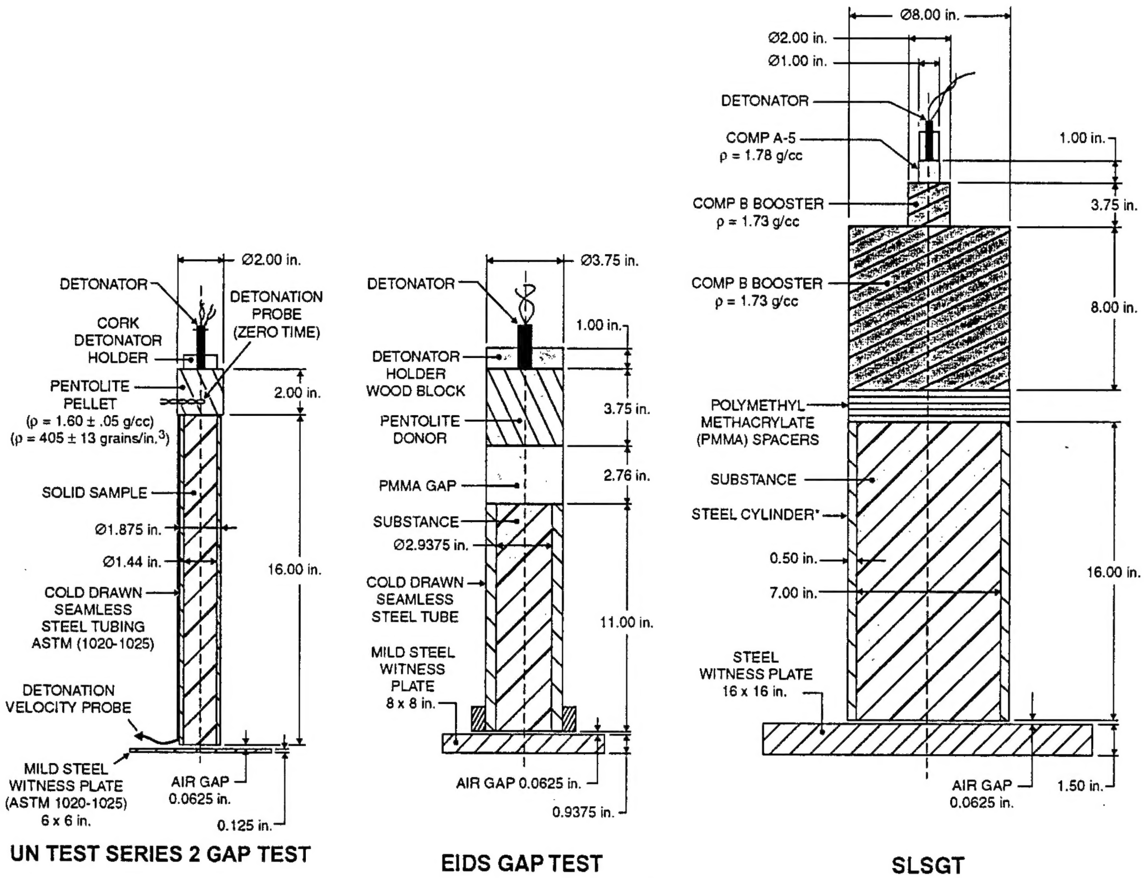
At the same meeting, a workshop was held to continue the technical discussion regarding the TB-700-2 "alternate test protocol" required for assigning a hazard classification for large (strategic & space booster sized) Solid Rocket Motors (SRMs). Discussions focused on addressing the current shock sensitivity test protocol and coming to a consensus on what the recommended configuration should be for a revised protocol. Specific items considered included: sample dimensions, input donor charge dimensions (diameter and length) and standoff distance (attenuation). Plans were also made to hold a workshop on developing a sub-scale fast cookoff test that could be correlated with the full-scale fast cookoff tests required TB-700-2, under UN Test Series 6.

This paper outlines the authors continuing efforts to unite the solid rocket community and through a series of workshops and cooperative efforts, develop acceptable alternate test protocols that could fulfill the intent of TB 700-2 and be considered by the DDESB for incorporation into a future revision to TB 700-2.

BACKGROUND

Concerns

In the first paper, we listed the following concerns the solid rocket community had with the revised TB-700-2. The United Nations (UN) test series 6 (which addresses storage and transportation hazards for class 1 hazard divisions), utilizes full size articles to test for internal ignition, external heating and shock sensitivity. This test series is cost prohibitive and impractical for large rocket motors. The current alternate tests in the protocol are inconsistent with UN test series 6 in that they don't address internal ignition or external heating. In addition, the alternate shock sensitivity tests are too extreme to represent actual transportation and storage threat concerns, imparting a shock stimulus to the propellant orders of magnitude higher than the worst-case scenarios. The configurations for the alternate gap tests (UN Series 2 gap test; Extremely Insensitive Detonating Substances – EIDS Gap Test; Super Large-Scale Gap Test – SLSGT) are shown in Figure 1. The zero cards requirement for all of the alternate gap tests, are also inconsistent with the Naval Ordnance Lab (NOL) card gap test used for Interim Hazard Classification (IHC) that uses



*MAY BE MACHINED FROM WELDED CARBON STEEL TUBING (1026) DRAWN OVER MANDRES (DOM), SPEC: A513

Figure 1. Alternate Test Series Gap Test Configurations

70 cards and the EIDS test in UN test series 5 that uses a 70.10-millimeter (2.76-inch) polymethyl-methacrylate (PMMA) gap for shock attenuation. The configuration for the NOL card gap test, which is often used in place of the UN Test Series 2 gap test, and is also known as the Large Scale Gap Test (LSGT), is shown in Figure 2.

As a result of the DoD hazard classification changes, many solid rocket propellants and motors will have an interim hazard classification of 1.3 and a final classification of 1.1. Many class 1.3 motors now in production would be reclassified as 1.1 if put into a new DoD system.

Thiokol, Air Force Research Laboratory Propulsion Directorate, Atlantic Research Corporation and Naval Air Warfare Center Position

Based on the notes from past JANNAF Propulsion System Hazards Subcommittee (PSHS) meetings, it was apparent that members of the Safety and Hazard Classification (SHC) Panel recognized the need for additional alternate tests to address the properties measured by those of UN Test Series 6. It appeared that

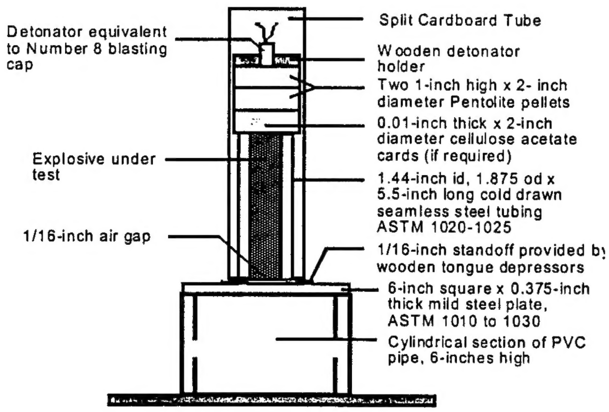


Figure 2. Naval Ordnance Lab (NOL) – Large Scale Gap Test (LSGT) Configuration

although other tests were discussed, a consensus could not be reached, so they were not recommended for incorporation into TB 700-2. The collaborative effort between Thiokol, Air Force Research Laboratory Propulsion Directorate, Atlantic Research Corporation and Naval Air Warfare Center was the first step at trying to reach a consensus for alternate testing.

In the first paper, we proposed three potential alternate tests (with nearly off-the-shelf test devices) we felt would adequately address the intent of TB 700-2, and yet not be prohibitively expensive. In TB 700-2's parent document (UN ST/SG/AC.10/11 "Recommendations on the Transport of Dangerous Goods") [3], paragraph 41.3.3 states that an alternate series of tests can be used if "The product including packaging can be unambiguously assigned to a hazard division by a qualified explosives expert on the basis of results from other tests or of available information."

Proposed alternate tests

The following three alternate tests address the storage and transportation concerns of internal ignition, external heating and shock sensitivity.

1. Internal ignition concerns:

Alternate test: As documented by the DDESB-KT memorandum of 7 Feb, 1999, a JANNAF proposal for using motor firing data for ignition function in lieu of single package hazard testing was approved by the tri-Service hazard classification group. This combined with item 3 below that addresses shock sensitivity should adequately address the purposes behind the single package tests from UN Test Series 6. This same DDESB-KT memo also states that 'large motors should be tested singly (if transported singly); however, storage configurations may require that multiple items be tested.' Thus, the stack test is not generally applicable to large solid rocket motors, and an alternate test protocol is probably not necessary.

2. External heating concerns:

Alternate test: Analog fast cookoff test. This would be essentially the same test called for in the current TB 700-2 Test 6(c), paragraph 5-7c [or the alternate test 6-6e(2)], but instead of being performed on a full-scale article, it would be performed on a subscale analog. The requirements for the analog would be that the thermal gradient during heating in a bonfire, the pressure within the vessel upon propellant ignition and the case burst pressure match the full-scale article as closely as possible. This could be accomplished by using the same case/insulation/liner/propellant materials used in the full-scale article, and by designing the analog case strength and opening size to match the nominal burst and operating pressures of the full-scale article. For a given burst strength, the case thickness of a small diameter article is less than that of a large diameter article, so without modification, the thermal gradient would be different. However, the analog case could be further insulated with non-structural case material to supply the proper thermal environment. The web thickness used in such an analog would be a matter for discussion, but something similar to the 203.20-millimeter (8-inch) diameter Shrike motor that the Navy has used for several years for IM testing should be sufficient. This motor would have the added benefit of a large existing database for comparison. The aforementioned DDESB memo states "Alternate test data such as subscale engulfing fire test is acceptable (if verified as a model) as replacement for bonfire test of full-scale test article. The alternate test article approach requires further work to justify its use." Thus the DDESB has already taken the position that an analog fast cookoff test is an acceptable alternate test in principle.

3. Shock sensitivity concerns:

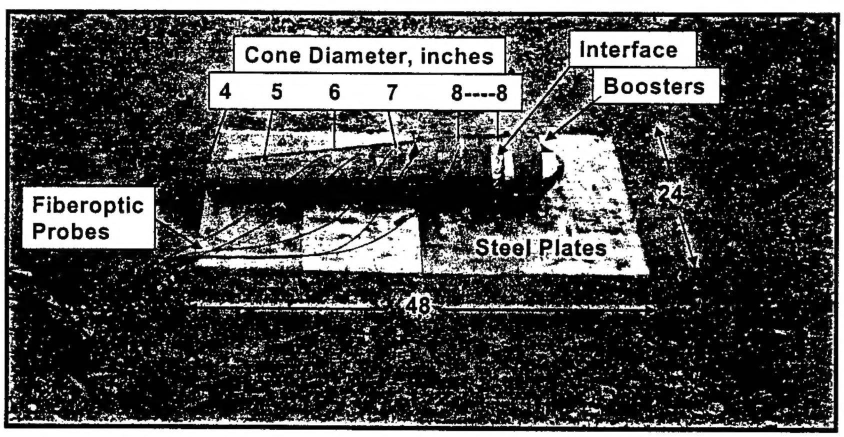
The only shock sensitivity test required by TB 700-2 for UN Test Series 6, is the detonator cap initiation on the first test run of the single package test. Many parties have expressed concern that this test is insufficient for discriminating between Hazard Division 1.1 and 1.3 articles. It is for this reason that the JANNAF Safety and Hazard Classification Panel developed the generic critical diameter and card gap test protocol for large rocket motor classification back in 1992. However, for whatever reason, gap tests with unrealistic shock stimuli (zero card requirements) were adopted instead. There is no possible credible event associated with storage, handling and transportation that corresponds to the >280 kbars [4] (4,061,056.83 psi) of shock the SLSGT applies to the propellant. If one were to insist on such a large diameter sample in order to address possible critical diameter concerns, it would be important to provide a more reasonable confinement and shock input to the sample than is currently required by the SLSGT. The original JANNAF intent to use critical diameter as a means for determining which shock sensitivity test to perform and to actually measure the shock pressure required for propagation (as measured by varying the gap) is a way of obtaining the data needed to allow experts to make informed decisions about the recommended shock sensitivity test configurations, sample dimensions, input charge dimensions and stand-off distance (attenuation).

Until the critical diameter testing can be completed, and a database can be generated, a practical approach would be to use the historical boundary between Class 1.1 and 1.3 propellants in regard to shock

sensitivity. This has been the 70-card NOL gap test at 70 kbars (1,015,264.21 psi) of shock stimulus over an area of 36.58 millimeters (1.44 inches). This represents an over estimated, conservative approach to potential threats, but has served the industry well for over thirty years. However, the shock input over a 177.80-millimeter (7-inch) ID area for a SLSGT should be similar in duration but significantly less in magnitude, certainly no greater than 5 kbars (72,518.87 psi). In order to achieve this exposure in the SLSGT, a gap of approximately 355.60 millimeters (14 inches) of polymethyl-methacrylate (PMMA) cards would be required to attenuate the magnitude of the shock from the booster charge down to that level. Additionally, the length of the booster charge would need to be shortened considerably from the 203.20 millimeters (8 inches) of the current SLSGT configuration to make the duration of the shock wave comparable to that of the NOL Gap Test. Similarly, if the EIDS test is utilized, it should have a reasonable shock stimulus such as the 70.10-millimeter (2.76-inch) PMMA gap used in UN Test Series 5. To address the issue of confinement, substitutes for the thick walled cylinders could be used. Many large-scale shock sensitivity and critical diameter tests have been conducted by the Air Force using cardboard cylinders.

Two other shock sensitivity tests could be used as a screening tool to assess critical diameter and gain insight into which diameters to test. They are the unconfined cylinder critical diameter test, which utilizes a sample 152.40 millimeters in diameter by 457.20 millimeters in length (6-inch x 18-inch). This configuration is shown in Figure 3. The second test is the conical critical diameter test that utilizes a 203.20-millimeter to 101.60-millimeter (8-inch to 4-inch), sample with a 4 degree taper, shown in Figure 4.

Figure 3. Unconfined Cylinder Critical Diameter Test



Pre-Test Setup

Figure 4. Conical Critical Diameter Test

For the present, a workable solution for shock sensitivity testing would include using the 70-card NOL LSGT gap test as a starting point. Then for those applications that have specific shock sensitivity/critical diameter concerns such as large motors with diameters greater than or equal to 304.8 millimeters (≥12 inches) with propellants containing energetic ingredients, shock sensitivity tests could be conducted and

reviewed by experts in detonation behavior. These tests could include modified versions of the EIDS and SLSGT with reasonable shock inputs as seen in Figure 5.

Since the writing of the first paper, two of the authors (Boggs and Graham) and Phillip Miller (China Lake) have been actively conducting shock sensitivity testing and modeling to address sample dimensions and attenuation. They presented their data and conclusions in a paper titled "New Shock Sensitivity Test Proposed for Hazard Classification"[7] (see APPENDIX A) at the Department of Defense Explosive Safety Board (DDESB) 29th U.S. DoD Explosives Safety Seminar. In the paper, Miller, Boggs and Graham outline alternative gap tests that could be used in place of the SLSGT and zero card criteria. Several different configurations are modeled, using several different energetic materials. Based on the calculations, recommendations are made for a more realistic replacement for the current gap tests called out in TB 700-2.

The following conclusions can be reached based on the computer simulations in this paper:

1. Propellant ignition and growth reactive flow models can be used to reproduce observed Gap Tests for 1.3 as well as 1.1 propellants.

2. The model can be a viable tool in designing alternative Gap Test configurations or any other 2-D shock ignition and reaction experiment representing propellant hazard events.

3. This work indicates that 90% solid loading of a typical ammonium perchlorate (AP), aluminum (Al), elastomeric binder propellant may be borderline in passing the zero cards SLSGT.

4. The use of a shorter length donor and a longer length acceptor with polyvinyl chloride (PVC) confinement rather then steel may be more realistic for determining the shock sensitivity of propellants.

5. The nitramine containing AP/Al/binder propellants will never pass the zero cards SLSGT and for any of these to be classified as a 1.3 hazard material, new standards will have to be determined.

Threat hazard assessment

Before initiating any test protocols for hazard classification, what is clearly needed is a thorough threat hazard assessment for the intended materials or articles. By assessing the potential storage and transportation threats the articles could be subjected to, the appropriate test protocols could be implemented to address the concerns of: internal ignition, external fire and shock sensitivity/critical diameter. For example, if the end item is a large rocket motor that would be singly shipped and stored. A stack test would not be required. Another example of an article requiring a threat hazard assessment would be, a large rocket motor containing nitramines such as RDX cyclotrimethylenetrinitramine or HMX (cyclotetramethylenetetranitramine). To adequately address the shock sensitivity/critical diameter concern, a conical critical diameter test, EIDS and SLSGT with a reasonable shock inputs would be called for, as well as a review by experts in detonation behavior.

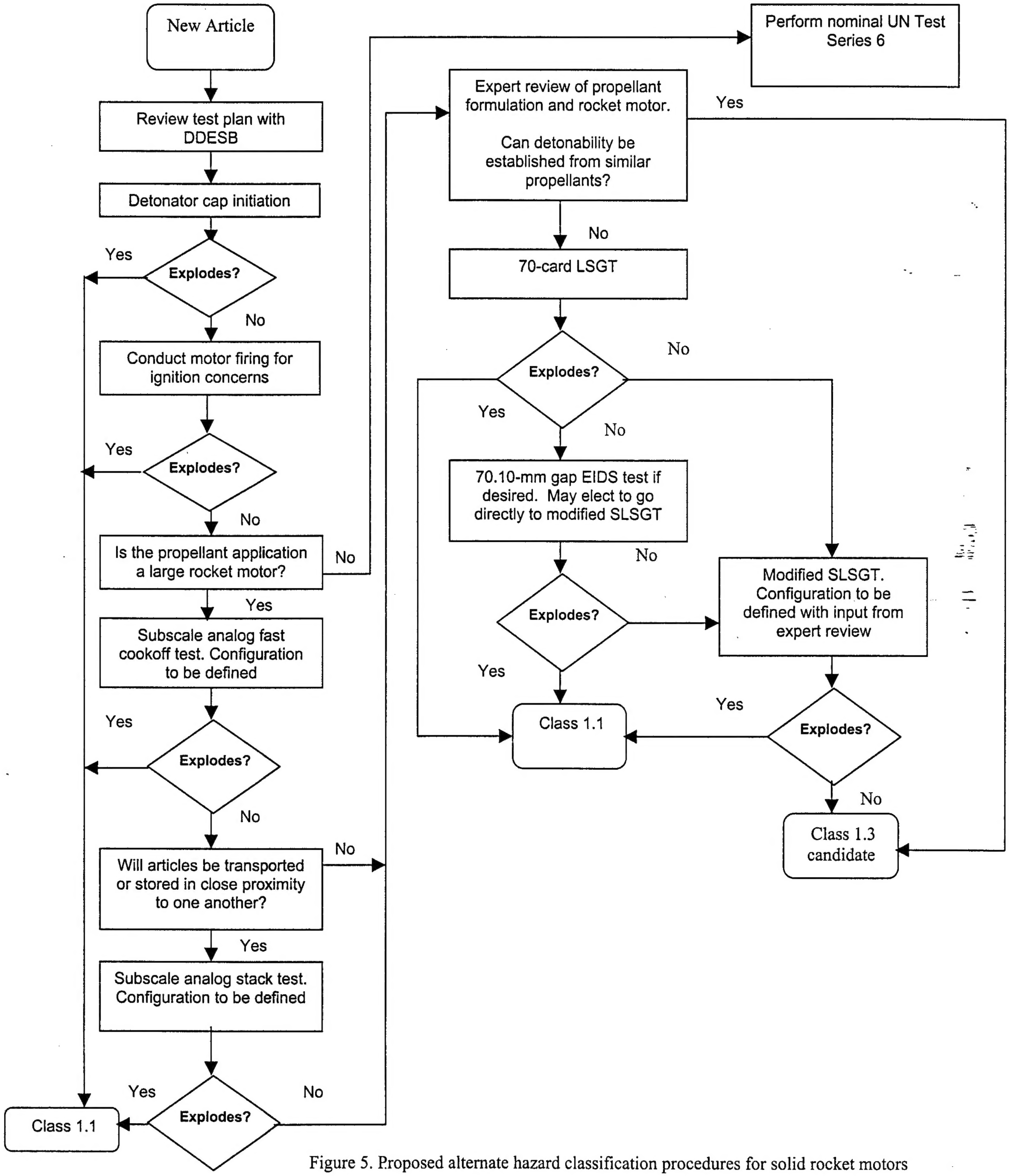


Figure 5. Proposed alternate hazard classification procedures for solid rocket motors

WORKSHOP/PANEL EFFORTS

99 JANNAF PSHS WORKSHOP

Formal efforts by the solid rocket community to improve and revise the current TB 700-2 began at the 1999 JANNAF PSHS Meeting (18-21 Oct 1999) held in Cocoa Beach. At this meeting Mr. Bill Thomas (SHC Panel Chairman) listened to discussions by panel members on possible improvements for the new hazard classification protocols for large rocket motors. Of particular concern to the panel members were the alternate shock sensitivity gap tests. The panel members were requested to submit their inputs to Mr. Thomas, who was tasked to give a summary at a workshop held at the upcoming JANNAF Joint Propulsion Meeting (JPM) in December.

99 JANNAF JPM WORKSHOP

In December of 1999 at the JANNAF 49^{th} Joint Propulsion Meeting (JPM) in Tucson, AZ, a joint workshop was held as a cooperative effort between the JANNAF PSHS and PDCS subcommittees to address the impact of the revised TB-700-2. The intent of the workshop was to take the attendees individual technical concerns, objections and recommended alternate test protocols and form a consensus position and recommendation to the DDESB and Tri-service DoD Hazard Classifiers.

While an overall consensus position was not reached, the workshop attendees agreed to recommend that TB 700-2 (1/5/98) alternate test protocol requirements be revised to include the following:

1. Continue NOL card gap test requirement of 70 kbar (1,015,264.21 psi), at 70 cards for obtaining a storage and transportation interim hazard classification.
2. Include a Safety Hazard Analysis in the TB 700-2 requirements prior to assigning a final classification of articles
3. One of the following approaches:
    a. Continue to require SLSGT sample size, hardware and test setup and revise the donor charge output to a "credible incident" value, i.e. from >280 kbars (>4,061,056.83 psi) to 2-3 kbars (29,007.55 - 43,511.32 psi).
    b. Continue to require SLSGT hardware configuration and include a significant separation [355.60 millimeters (14 inches) of PMMA] between the sample and the donor charge to attenuate the donor charge output to a "credible incident" value (from >280 kbars to 2-3 kbars).
4. Revise the test set up requirements to specify a 70 kbar donor charge and not change from the zero card requirement. This would require actual testing to validate the revised donor charge, however, it could be accomplished in a short period as a round robin JANNAF activity. Several members of the workshop prefer this approach because it is consistent with the US/NATO NOL card gap test requirements. Include a Safety Hazard Analysis in the TB-700-2 requirements prior to assigning a final hazard classification of articles.
5. Eliminate the required SLSGT from the alternate test protocol and revise TB 700-2 (1/5/98) to include a different testing method of determining the critical diameter of the propellant. The requirement to conduct the NOL card gap test for an interim hazard classification should remain the same.

00 JANNAF PDCS WORKSHOP

Further efforts to unite the solid rocket community into forming a consensus and developing standardized hazard protocols were continued at the JANNAF PDCS & SEPS Joint Meeting (8-12 May 2000) held in Cocoa Beach, FL. A workshop was held to specifically address what the recommended configuration of a shock sensitivity test should be. Items considered included sample dimensions, input charge dimensions (diameter and length) and stand-off distance (attenuation). The consensus of the workshop was that all of the shock sensitivity tests should be attenuated down to 70 kbars as a minimum and possibly much lower for the SLSGT. In addition, the test data from the SLSGT supports the belief that the sample length needs to be doubled to allow either the propagation of a stable detonation reaction or the decaying of the reaction to sonic velocities.

00 DDESB EXPLOSIVES SAFETY SEMINAR WORKSHOP

The most recent efforts at revising TB 700-2 took place at the Department of Defense Explosive Safety Board (DDESB) 29th U.S. DoD Explosives Safety Seminar in New Orleans, LA from 18-20 July. On 19 July 2000 a workshop was held on the subject of bonfire testing for rocket motor hazard classification. This workshop addressed one of the concerns the solid rocket community has with the TB 700-2 test protocols i.e. the UN Test Series 6 (mandatory for hazard divisions 1.1, 1.2, 1.3 and 1.4), which requires full-scale articles testing for the tendency of an article to explode when heated by an external fire to destruction.

In our first paper, we recommended sub-scale analogs be considered as an alternative to full-scale testing. However, in a previous meeting with Dr. Jerry Ward and Dr. Josephine Covino from DDESB, Dr. Ward stated he had serious concerns that a proposed sub-scale analog test could not adequately predict what would happen in the full-scale article test. After much discussion, it became clear that the DDESB wants test and modeling data directed toward verifying that sub-scale analog testing can predict the reaction of full-scale articles to fast cookoff testing. The purpose of this workshop was to specifically address the questions of:

> Can a subscale analog cookoff specimen be designed, tested and modeled to give the DDESB confidence that subscale tests can adequately mimic full-scale articles?
>
> Can data be provided giving confidence that motors containing propellant having NOL card gap test sensitivities in the range of 0 (barely) to 69 cards will not detonate in external fire cook-offs?

Quantitative uncertainty about the explosive hazard of items containing Class 1.3 propellants having explosive sensitivity near the Class 1.1 and 1.3 separation (70 cards sensitivity by the NOL gap test) in fire environments has prompted those with hazard classification responsibility (DDESB, military service hazard classifiers) to try making items filled with more explosively sensitive Class 1.3 propellant much safer than permitted in the past. Items considered included analog motor dimensions and how to best match full-scale articles in terms of propellant properties, case burst pressure, case and insulation materials, and detonation propensities during cookoff events.

Present at this workshop were all of the authors of this paper, Dr. Josephine Covino (DDESB), Mr. Eric Olson (Air Force Hazard Classifier), Dr. Marvin Jones (Pratt & Whitney Chemical Systems Division), Dr. Garn Butcher (Alliant TechSystems), Mr. Bill Thomas (SHC Panel Chairman) and. Dr. Claude Merrill (Air Force Research Laboratory Propulsion Directorate). Thus, good representation was present for hazard classifiers, propulsion hazard expertise, and the rocket propulsion manufacturers.

At the workshop, Dr. Merrill presented his proposal for a sub-scale motor explosive hazard classification test program for storage and transportation using external fire tests (see APPENDIX B) [8]. He suggested that two propellants be tested. One with at barely 0 cards explosive sensitivity by the NOL gap and one with 60 to 69 card explosive sensitivity as measured by the NOL gap test. He also suggested that sub-scale test motor size be 304.8 millimeters (12-inches) in diameter making them much larger than the approximate explosive critical diameters of the two propellants, ~63.50 millimeters (2.5 inches) and ~25.40 millimeters (1-inch) respectively, so that propensity for detonation would be adequately retained in the sub-scale test motor. Full-scale motors using the same propellant and insulation materials, perhaps in two sizes, e.g., larger than 762-millimeter (30-inch) diameter, and 1,524-millimeter (60-inch) diameter or more would be tested to correlate behavior due to changes in motor size. Further, the sub-scale rocket motors were to be tested under the most arduous probable conditions for storage and transportation fires where motors that case burst during cook-off reactions could have motor and propellant fragments impact nearby hard structures, such as steel beams. Since solid rocket propellants are designed to have stable burning at very high pressures, they are essentially impervious to detonation prompted by motor pressures that would be involved in rocket motor case bursting cook-off events. However, concerns remain about whether burning motor/propellant fragments propelled by case bursts can be shocked to detonation by impacts upon nearby hard structures. Sub-scale motors having thinner propellant web thicknesses than full-scale motors might be more likely to produce shock to detonation results since lighter weight web fragments could be accelerated to higher speeds than for larger propellant web thickness rocket motors. The outcomes of the proposed test program will determine whether the traditional explosive sensitivity divide at 70 cards NOL card gap sensitivity is adequate for rocket motor safety in storage and transportation fires. Additional data about atmospheric overpressures and fragment and firebrand throw distances would help hazard classifiers judge where limitations on these traits should be.

The Air Force Hazard Classifier, Mr. Olson, voiced his concerns that a sub-scale analog test could not reproduce the full-scale motor reaction and possible fragment hazards. Mr. Olson went on to state that even if the alternative shock sensitivity tests to UN Test Series 6 are done, they technically don't get you out of the requirement for a full-scale stack test. This seems a reversal from what has been said in past hazard classification seminars and workshops. When questioned why full-scale bonfire tests were never required in the past, Mr. Olson stated they assumed the motor fragment hazards based on analogy to similar propellants/motors, for example, generic AP/Al propellants with hydroxy-terminated polybutadiene (HTPB) binders. He indicated that for the new higher energy propellants such as those being developed

under the Integrated High Payoff Rocket Propulsion Technology (IHPRPT) program this would not be an option if they were put into a fielded system.

The consensus of the workshop was that efforts to develop, test and model a sub-scale analog are not only worth-while, but of vital importance to the solid rocket community, especially since at least one full-scale bonfire test may be required under the current TB-700 guidelines. The group agreed that the starting point for this effort should begin with the extensive database the Navy generated on the 203.20-millimeter (8-inch) diameter Shrike motor for insensitive munitions (IM) testing. Cook-off data for Class 1.3 propellants having NOL card gap sensitivities in the range of 0 to 69 cards may be lacking in the China Lake database. Mr. Jim Cocchiaro from Johns Hopkins University-Chemical Propulsion Information Agency (CPIA) said he would try to retrieve this data from JANNAF reports and make it available to the workshop participants. The participants will then determine what additional testing will be needed. A follow-on workshop will be held at the JANNAF PSHS Joint Meeting (13-17 Nov 2000).

00 JANNAF PSHS SHC PANEL MEETING

On 20 Jul, a subsequent meeting was held at the conference with members of the JANNAF PSHS, SHC Panel, Tri-Service Hazard Classifiers and Dr. Jerry Ward and Dr. Josephine Covino from DDESB. The purpose of the meeting was to submit the inputs and recommendations from the principal panel members to the DDESB and Tri-Service Hazard Classifiers regarding possible revisions to TB 700-2. The main topic of discussion was the current alternate test protocol to UN Test Series 6 (Shock sensitivity gap tests). The concern with the current alternate test protocols is the zero card requirements for all the shock sensitivity tests to obtain a 1.3 designation. These tests represent an unrealistic shock stimulus imparted to the propellant (>280 Kbar). The standard NOL test at 69 cards (The old determination for a class 1.3 designation) imparts 70 Kbar of stimulus to the sample. Calculations have shown the worst-case scenario for shock imparted to a rocket motor during transportation is less than 1 Kbar. The SHC Panel recommended either modifying the alternate gap tests (UN Series 2 gap test or LSGT, EIDS and SLSGT) to allow the amount of cards needed to attenuate the shock down to the 70 Kbar level or revise the test set up requirements to specify a 70 kbar donor charge and not change from the zero card requirement. This would require actual testing to validate the revised donor charge, however, it could be accomplished in a short period as a round robin JANNAF activity. Several members of the workshop prefer this approach because it is consistent with the US/NATO NOL card gap test.

Ms. Pat Vittitow (U.S. Army Space Missile Defense Command) strongly urged against modifying the current gap tests. Ms. Vittitow's concern was that changing the zero card requirement for the gap tests would allow propellants with a small critical diameter to be placed in large rocket motors where the web thickness could exceed the critical diameter. She stated a propellant should not be detonable under any circumstances. The majority of the panel members pointed out that the current gap tests were not critical diameter tests and given a propellant sample with a large enough diameter and hit with a sufficient

stimulus, any propellant could be made to detonate. Panel members stated they believed that propellant in an explosive Class 1.3 rocket motor should not be detonable under credible, real world storage and transportation scenarios. Since the major risk for rocket motor storage and transportation is external fires impinging upon the rocket motors, a study of fire effects on rocket motors filled with more explosively sensitive Class 1.3 motors is needed to resolve questions about their safety.

Also discussed was the issue of what size diameter is most relevant for determining a rocket motor's critical diameter. Some panel members believed the motor web thickness was sufficient, while others took a more conservative view, stating that motor diameter plus 10% was needed. This view observes that you get a double shock process when a perforated propellant grain is shocked from one end. The first shock is direct upon the end of the propellant grain and the second shock occurs when broken propellant stops at the opposite end of the propellant grain. Two of the authors (Boggs and Graham) again made the point that critical diameter is not the all-encompassing factor for determining a rocket motor's propensity to detonate. Critical diameter testing requires a planar shock wave from the donor charge be transmitted to the full diameter of the propellant acceptor. Once above a certain small size diameter, planar shock doesn't represent a credible threat. Likelihood of a large diameter rocket motor receiving a planar shock in a real-world storage condition becomes inconceivable.

Mr. Graham elaborated on the subject with a brief presentation that addressed several of the issues brought up in the meeting. He stated there is no direct, functional relationship between critical diameter and shock sensitivity of many propellants. He went on to say that the Project Sophy data on critical diameter as a function of nitramine content does not apply to the modern increased energy propellants such as those being developed for IHPRPT. The Sophy data used polybutadiene-acrylic acid-acrylonitrile (PBAN) binder propellants with 30 μm RDX. The current IHPRPT propellants utilize HTPB binders and approx 2 μm RDX, significantly reducing the shock sensitivity. Mr. Graham suggested that a thorough test program to resolve some of the issues associated with hazard classification of large motors should test for burn rate at high pressures, shotgun/relative quickness, and critical diameter versus shock sensitivity relationships for a variety of propellant formulation families.

After all the discussions were over, it came time for the Tri-Service Classifiers to give their inputs and recommendations on critical diameter and shock sensitivity testing. Mr. Mark Skogman (Army Hazard Classifier) stated he was undecided if the propulsion community could adequately determine where the Hazard Division 1.1 and 1.3 threshold is for propellants in large rocket motors. Mr. Ed Walseman (Navy Hazard Classifier) was absent, but sent word that he indorses a 70 Kbar shock input for the three gap tests with additional testing to determine critical diameter. In addition Mr. Walseman supported the JANNAF workshop efforts to develop, test and validate subscale bonfire testing for the hazard classification of large rocket motors. Mr. Eric Olson (Air Force Hazard Classifier) said at this time he tends to agree with Pat Vittitow in keeping the current zero card requirement for the three gap tests. He stated he does not feel the

SLSGT is an unreasonable shock sensitivity test, but that it could benefit by doubling the length to 32 inches. However, Mr. Olson did say he was undecided as to what motor diameter is large enough to disregard propellant critical diameter. He also wanted to know what test geometry is important in ascertaining critical diameter.

When it seemed a consensus would not be reached, Dr. Josephine Covino (DDESB) stated that rather than make a ruling at this time, she would advocate further testing to address the concerns of the panel members and hazard classifiers and look into getting funding to support these efforts. She also indicated that threat assessment or risk analysis should be part hazard classifying large rocket motors. Dr. Jerry Ward (DDESB) indicated he also favored further research and development efforts for shock sensitivity testing and development of a subscale bonfire test protocol for large rocket motors. The DDESB tasked JANNAF to pursue the development of a program/test plan to investigate these issues. Details should be available and reported at the JANNAF PSHS Joint Meeting (13-17 Nov 2000).

CONCLUSIONS

The UN test series 6 used to address storage and transportation hazards for class 1 hazard divisions utilize tests for internal ignition, external heating and shock sensitivity. This test series requires full size articles and is cost prohibitive and impractical for large rocket motors. The current alternate tests in the protocol are inconsistent with UN test series 6 in that they don't address internal ignition or external heating. In addition, the alternate shock sensitivity tests are too extreme to represent actual transportation and storage threat concerns, imparting a shock stimulus to the propellant orders of magnitude higher than the worst-case scenarios. The zero cards requirement for all of the alternate tests are also inconsistent with the NOL card gap test used for IHC that uses 70 cards and the EIDS test in UN test series 5 that uses a 70.10-millimeter PMMA gap for shock attenuation.

As a result of the DoD hazard classification changes, many solid rocket propellants and motors will have an interim hazard classification of 1.3 and a final classification of 1.1. Many class 1.3 motors now in production would be reclassified as 1.1 if put into a new DoD system.

Before initiating any test protocols for hazard classification, a thorough threat hazard assessment is needed for the intended materials or articles. By assessing the potential storage and transportation threats the articles could be subjected to, the appropriate test protocols could be implemented to address the concerns of: internal ignition, external fire and shock sensitivity/critical diameter.

For the present, potential subscale alternate tests have been identified and proposed by members of the solid rocket community that address the properties measured by UN Test Series 6, i.e. internal ignition, external heating and shock sensitivity in a cost effective, representative, test protocol. To further assess shock sensitivity/critical diameter concerns, critical diameter tests, modified gap tests with reasonable shock stimuli and expert reviews for high-energy propellants offer a fair, more representative, test protocol to the alternate shock tests currently under TB 700-2.

To unite the solid rocket industry to come to consensus and recommend new test protocols for a revised TB 700-2, workshops have been conducted at the appropriate JANNAF subcommittee meetings with representatives from each of the organizations affected by TB 700-2 and from experts in the field of detonation test designs and modeling. The past workshops have addressed such issues as recommended shock sensitivity test configurations, sample dimensions, input charge dimensions and stand-off distance (attenuation). Future workshops will report the ongoing shock sensitivity testing being conducted by the government labs and industry, the relation of critical diameter to the hazard classification of large rocket motors and the design and correlation of subscale analog fast cookoff test articles with full-scale articles.

REFERENCES

1. Department of Defense (DoD) Ammunition and Explosives Hazard Classification Procedures Joint Technical Bulletin TB 700-2/NAVSEAINST 8020.8B/TO 11A-1-47/DLAR 8220.1; 5 January 1998

2. Bennett, R.R., Schwartz, D.F., Graham, K. J., and Boggs, T.L., "Comments and Position Regarding the Joint Technical Bulletin 'Department of Defense Ammunition and Explosives Hazard Classification Procedures' TB 700-2, dated 5 January 1998." JANNAF 29th PDCS Meeting, CPIA Publication 697, Vol. 1, 2000.

3. Recommendations on the Transport of Dangerous Goods – Manual of Tests and Criteria, ST/SG/AC.10/11 Rev 2 Dated 1995

4. Safety and Performance Tests for the Qualification of Explosives (High Explosives, Propellants and Pyrotechnics, NIL-STD-1751A Draft Dated December 1992

5. Boggs, T.L., Atwood, A.I., Lindfors, A.J., Mulder, E.J. and Pritchard, R.W., "Hazards Associated With Solid Propellants", JANNAF 17th Propulsion Systems Hazards Subcommittee Meeting Vol 1, CPIA Publication 681, Volume 1, pp. 157-198, December 1998

6. Mulder, E.J., "Summary JPM Workshop on TB-700-2 (1/5/98)", JANNAF 49th Joint Propulsion Meeting December 1999.

7. Miller, P.J., Boggs, T.L. and Graham, K. J., "New Shock Sensitivity Test Proposed for Hazard Classification" , Proceedings of the 29th DoD Explosives Safety Seminar held in New Orleans 18-20 July 2000

8. Merrill, C. I., "Motor Explosive Hazard Classification Test Program for Storage and Transportation", Workshop at 29th DoD Explosives Safety Seminar held in New Orleans 18-20 July 2000

APPENDIX A

New Shock Sensitivity Test Proposed for Hazard Classification

Philip J. Miller and Thomas L. Boggs
Naval Air Warfare Center Weapons Division
China Lake, California

Kenneth J. Graham
Atlantic Research Corporation,
Gainesville, Virginia

ABSTRACT

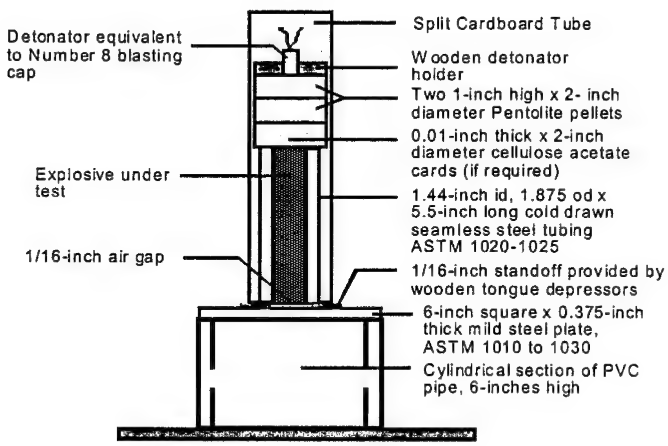
Many have expressed concerns over the alternate hazard classification test protocol currently called out in the Department of Defense Ammunition and Explosives Hazard Classification Procedures, document TB 700-2 (Army), NAVSEAINST 8020.8B (Navy), TO 11a-1-47 (Air Force). One of the oft heard complaints is that the protocol calls out tests that are "over-kill" and not representative of actual credible safety and hazard events associated with storage, handling and transportation of energetic materials and articles. The Super Large Scale Gap Test (SLSGT), and the associated zero card criteria, has especially come under fire. This paper discusses alternative gap tests that could be used in place of the SLSGT and zero card criteria. Several different configurations are modeled, using several different energetic materials. Based on the calculations, recommendations are made for a more realistic replacement for the current gap tests called out in TB 700-2.

INTRODUCTION

When the Department of Defense Explosive Safety Board revised its Technical Bulletin 700-2 (also NAVSEAINST 8020.8B, Air Force TO 11A-1-47, and Defense Logistics Agency DLAR 8220.12) in January 1998, it significantly changed the procedures for determining the explosive hazard classification for motors to be shipped, handled and stored. The changes were made in attempt to provide alternative tests to the United Nations test series 6. The alternate tests consisted three different sized gap tests, all run at zero gap. The tests were the United Nations Series 2 gap test, the United Nations test for Extremely Insensitive Detonating Substance (EIDS) test (again at zero gap), and the 7 inch diameter Super Large Scale Gap Test (again at zero gap). The test description are depicted in Figure 1, and more fully described in Reference 1 (Bennett, Schwartz, Graham, and Boggs). A detonation in the UN Series 2 test with zero

gap, automatically gives the propellant a 1.1 rating. A no go means that the propellant must be tested in the EIDS zero gap configuration. A go (detonation) automatically gives the propellant a 1.1 rating, while a no go means that the propellant must be tested in the zero gap SLSGT. Again, a detonation automatically gives a 1.1 hazard classification, while a no go means that the propellant is a candidate for 1.3 hazard classification.

Almost from the time the "new" TB 700-2 was issued, there was wide spread controversy and discussion. There have been several meetings to discuss TB 700-2 (See Reference 1 for some of the background).



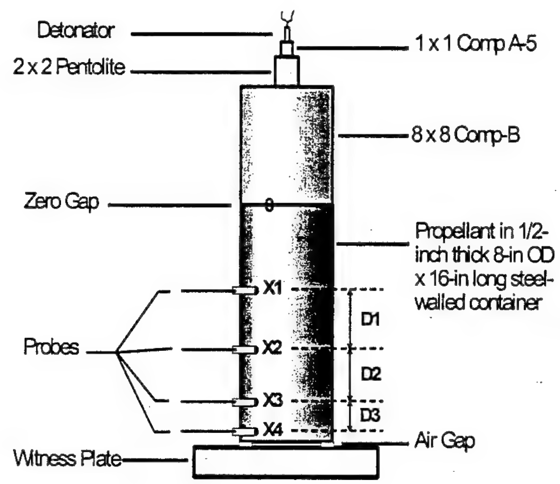


Figure 1. Drawings of the NOL-LSGT and the SLSGT.

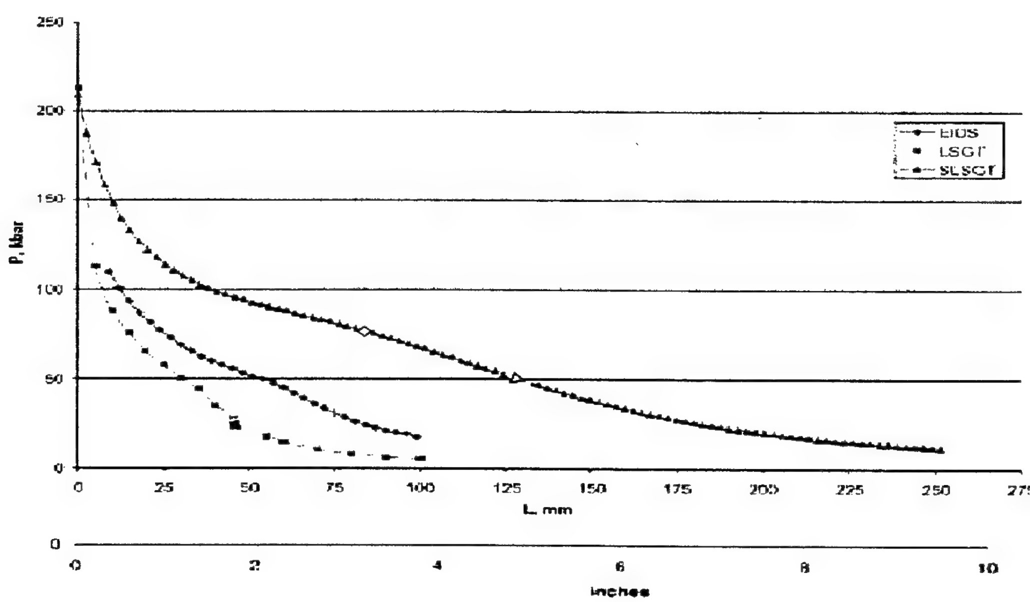


Figure 2. Experimental calibration curves for the Gap Tests.

Much of the discussion has surrounded the above series of tests and criteria. As discussed in Reference 1, there seems to be almost unanimous consensus that:

1) The zero gap SLSGT is a tremendous "over-kill" and does now correspond to any credible hazard scenario associated with shipping, handling, or storing missile motors.
2) Shock loadings associated with shipping ,handling, and storage are in the less than 3 kilobar range, not the well over 200 kilobars of the zero gap SLSGT.
3) Specific deficiencies of the SLSGT include the very large booster at zero gap, heavy confinement from the ½ inch thick steel walls
4) The very short length of the SLSGT coupled with the very high shock loading from the large donor at zero gap.
5) The SLSGT (and other gap tests) need to be modeled alternative tests may need to be proposed.

The purpose of this report is to report on progress that we have made on modeling the various gap tests, with various combinations of donors and gaps, and modeling a proposed alternative test.

COMPUTER SIMULATIONS

In developing a computer model to be able to simulate the gap tests, it is required that the experimental calibration curves for the gap pressure be successfully reproduced. We have used a modified version of the DYNA2D hydrocode that can be run on a desktop PC. This code contains the necessary subroutines to simulate these gap tests. The equation of states (EOS) for the donor explosives and the Gruneisen parameters for the steel and gap materials are listed in Table 1. The JWL EOS's were determined from experimental Cylinder Test expansion data. An extensive investigation by Bernecker (ref. 2) of various reported Hugoniots for PMMA, demonstrated that the experimental calibration curves can be reproduced by hydrocode simulations to within a 1% deviation and in this work the simulated and experimental calibration curves are virtually indistinguishable within the experimental error (Figure 2).

Table 1.

JWL Parameters for Donor Explosives

	ρ_o (g/cc)	A (Mbar)	B (Mbar)	R_1	R_2	ω	E_o (Mbar-cc/cc)
Pentolite	1.56	4.45	0.058	4.5	1.1	0.35	0.072
Comp B	1.717	5.242	0.768	4.2	1.1	0.34	0.085

Hugoniot Parameters for Steel and PMMA

	ρ_o (g/cc)	C (mm/μs)	S_1	Γ
Steel	7.90	4.47	1.49	1.93
PMMA	1.180	2.561	1.595	1.0

Propellants Investigated

The propellants investigated in this report are listed in Table 2. There are two 1.3 propellants (88% solid loading AP/Al/binder and 90% solid loading AP/Al/binder), one 1.1 (a high HMX content), and a nitramine-containing AP/Al/binder propellant that passes the 70 cards criteria in the LSGT, but fails at zero cards in the SLSGT. For input into the DYNA2D hydrocode, the Hugoniots are required to be in a JWL Gruneisen form. The converted U-u data are shown in Table 3. It is interesting to point out that the limited experimental data indicates that the experimental Hugoniot curves for the 88% and 90% solid loading AP/Al/binder propellants are nearly parallel with the 90% solid loading propellant having a greater sound speed then the 88% propellant, each being not too different from that of pure AP, Figure 3.

Table 2.

Propellants Investigated

	Generic Formula	Density g/cc	Hugoniot	Computed Failure Diameter
Propellant A	88% Solids loading AP/Al/Binder	~1.80	U_s=2.1+2.0u_p	>> 20 inches
Propellant B	90% Solids loading AP/Al/Binder	~1.85	U_s=2.4+2.15u_p	~ 16-20 inches
Propellant C	AP/Al/12%HMX/Binder	~1.85	U_s=2.4+2.15u_p	~ 2-2.5 inches
Propellant D	High HMX 1.1	~1.84	U_s=1.81+3.81u_p	< 1 inch

Table 3

JWL Unreactive Hugoniot Parameters*

	Propellant A	Propellant B	Propellant C	Propellant D
A **Mbars**	70.0	317.0	40.66	531.9
B **Mbars**	-0.01674	-0.00259	-1.339	-0.02979
R_1	10.0	10.947	7.2	12.0
R_2	1.0	-1.559	3.6	1.2
ω	0.8	0.912	0.83	0.8
C_v Mbar/K	2.5e-5	2.5e-5	2.5e-5	2.5e-5

*Determined by fitting 'time of arrival' data from embedded gauge experiments and the measured U_s-u_p Hugoniot data. For these calculations, the DYNA2D material constants were given as g=0.0354, sigy=0.002.

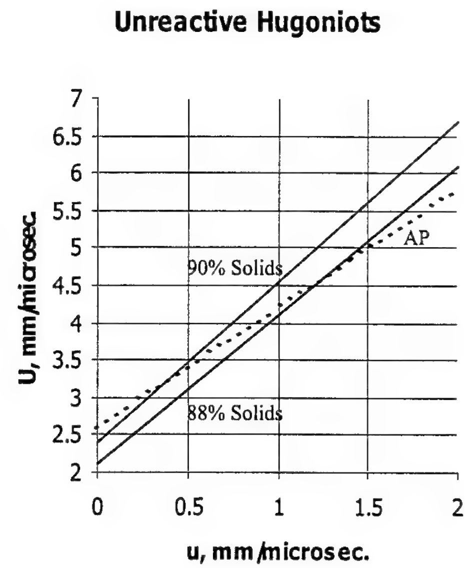


Figure 3. Measured Hugoniots of the AP/Al/HTPB propellants shown in comparison to AP, pressed to 98% TMD, (ref. 9).

Reactive Flow Model

A reactive flow hydrodyamic computer code model consists of an unreacted energetic material equation of state; a reactive product equation of state; a reaction rate law that governs the chemical conversion of energetic molecules to reaction product molecules; and a set of mixture equations to describe the states attained as the reactions proceed. The unreacted equation of state is normalized to shock Hugoniot data. The reaction product equation of state is normalized to expansion data, such as that obtained in a cylinder test or to calculated detonation states using thermal equilibrium codes (ref. 4). The latter has been carried out here assuming that the aluminum is inert in the reaction front or detonation state. These results are shown in Table 4. The reaction rates are inferred from embedded gauge and/or laser interferometric measurements of pressure and/or particle velocity histories. In these simulations the growth rate terms for the slow reactions were obtained from our previous studies on similar propellants (ref. 5 and 6). The parameters for the fast growth rates were obtained from a previous study of a similar propellant containing 14% HMX (ref. 7 and 8). Only the rate constant G_2 was varied a small amount to fit the experimentally obtained data. The parameters used are shown in Table 5. The ignition and growth reactive flow model has been normalized to a number of one- and two-dimensional shock initiation and self sustaining detonation data for high explosives, but little work has been reported on propellants. In this reactive flow formulation, the unreactive and product equation of states are both in the JWL (Gruneisen) form:

$$P = A\exp(-R_1V) + B\exp(-R_2V) + \omega C_vT/V, \quad (1)$$

where P is pressure; V is relative volume; T is temperature; and A, B, R_1, R_2, ω (the Gruneisen coefficient); and C_v (the average heat capacity) are constants. The ignition and growth reaction rate law is of the form:

$$\partial F/\partial t = I(1-F)^b(\rho/\rho_o-1-a)^x + G_1(1-F)^cF^dp^y + G_2(1-F)^eF^gp^z, \quad (2)$$

where F is the fraction reacted; t is time; ρ_o is the initial density; ρ is the current density; p is the pressure in Mbars; and I, G_1, G_2, b, x, a, c, d, y, e, g, and z are constants. The first term in Equation (2) controls the initial rate of reaction ignited during shock compression and is limited to fraction reacted $F \leq F_{igmax}$. The second term in Equation (2) is used to simulate the relatively slow growth of hot spot reactions during low pressure shock initiation calculations, and the third term is used to rapidly complete the shock to detonation transition in those calculations.

Table 4

JWL Reactive Hugoniot Parameters*

	Propellant A	**Propellant B**	**Propellant C**	**Propellant D**
A **Mbars**	17.714	17.015	19.078	7.82
B **Mbars**	0.1001	0.0954	0.1060	0.102
R_1	5.89	5.74	5.93	4.8
R_2	1.25	1.2	1.26	1.0
ω	0.28	0.3	0.27	0.27
$\mathbf{E_o}$ Mbar-cc/cc	0.0763	0.0786	0.0778	0.072
$\mathbf{C_v}$ Mbar/K	7.73e-5	7.73e-5	7.73e-5	1.0e-5

* Determined from thermochemical equilibrium Calculations, (for purposes of this work, the aluminum is considered to be inert in the reaction front).

Table 5

Reactive Flow Parameters*

	Propellant A	**Propellant B**	**Propellant C**	**Propellant D**
I	1.1	1.1	40.0	50
a	0	0	0	0
b	2/3	2/3	2/3	2/3
x	4	4	4	4
G_1	0.2	0.2	3.1	1150
y	1.0	1.0	1.0	3.0
d	1/9	1/9	1/9	2/9
c	2/3	2/3	2/3	2/3
G_2	5	5	8	0
z	2	2	2	0
g	1/9	1/9	1/9	0
e	1	1	1	0
F_{igmax}	0.015	0.015	0.015	0.15
F_{g1max}	1	1	0.12	1

*The origin of these parameters described in the text.

Gap Test Simulations

The gap tests are simulated by initiation of the donor explosive from a point and then allowing the donor to react at a constant CJ velocity and pressure. The pressure wave transmits into the PMMA gap and then in turn into the acceptor propellant. Since the Hugoniot for the propellant is much steeper then that for the gap material, there is a pressure jump across their boundary, and the resultant pressure in the propellant is as much as 10% higher than that determined from the calibration curves. Once the shock wave enters the propellant it is ignited, and then either builds to a detonation velocity or fades to its sound velocity. In the simulations, a 'fail or go' is defined as when the computed reaction velocity is stable, supersonic, and near the calculated detonation velocity of the propellant. A 'pass or no-go' is when the computed reaction velocity fades to the sound velocity in the propellant. The reaction velocities are computed from the 'time of arrival' of the reaction wave front at various locations (Figure 4) down the acceptor propellant length. Figure 5 shows the computed SLSGT results compared to the actual observed for the 88% solid loading AP/Al/binder propellant. The figure also shows the predicted SLSGT results for the 90% solid loading as well. It is interesting to point out that the only difference in the two calculations is the unreactive Hugoniot and the density. Apparently, the increased shock velocity in the denser material results in the critical

diameter of the material to be decreased by changing the manner in which the rarefactions quench the reaction front, hence, the 90% solid loading propellant detonates in the SLSGT at zero cards. (However, it does not detonate when the gap is increased to about 25-50 cards indicating that it is borderline to being a 1.3 propellant.) The computed failure diameters are 16-20 inches for

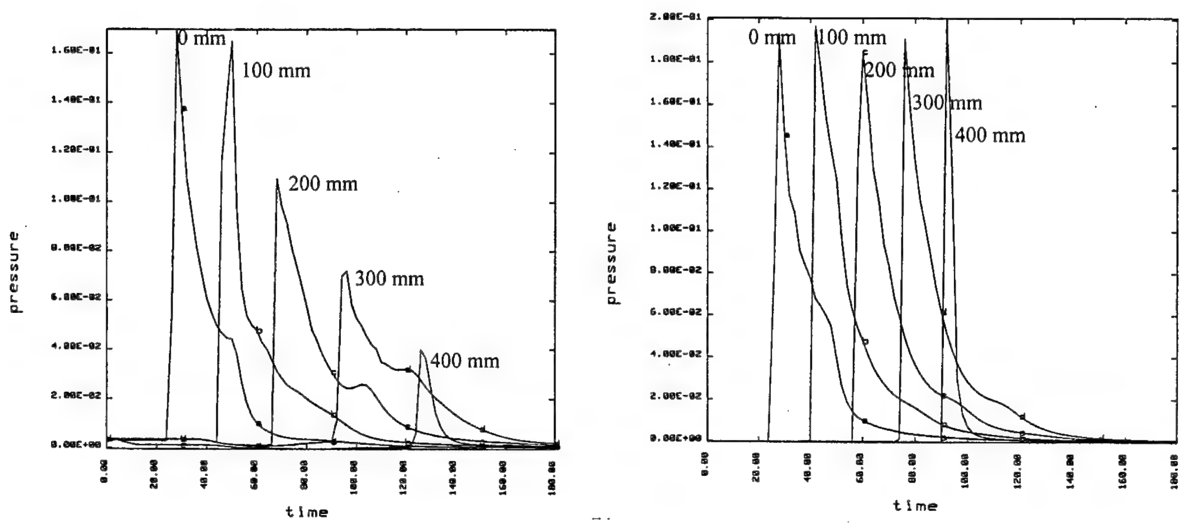


Figure 4. Computed pressure pulses for a fading reaction rate and a stable supersonic Detonation-like reaction at various locations in the acceptor propellant.

the 90% loading and much greater then 20 inches for the 88% loading. This observation needs to be verified by experiment, since these results for the 90% solid loading are borderline and very dependent on the measured unreactive Hugoniot. We also show the computed and observed SLSGT results for the AP/Al/12%HMX/binder propellant, which are in good agreement. Table 6 contains a summary of the simulations for each propellant in the three different gap test configurations carried out for this report. The computed results agree with the limited experimental data (ref. 10-13) that are available (as they should, since the experimental data from the SLSGT were used to refine the model).

Variations in the SLSGT Test Configuration

Several variations in the test configuration were tried. These included reducing the size of the donor explosive from an 8 inch diameter by 8 inch length to 8 x 4 inches. This reduction in size had no apparent effect on the computed SLSGT results. We also carried out simulations where the steel used to confine the propellant was replaced with PVC. The effect here was to make the 88% solid loading propellant fade faster down its length and allow the 90% solid loading sample to not detonate in the test at zero cards (Figure 6.). There was no apparent effect on the 12%HMX containing AP/Al/binder propellant. The use of PVC confinement is probably more realistic for an actual rocket motor, than the heavy steel confinement. The PVC material has an impedance much less then steel and is closer to the propellant. However, the

fragmenting PVC case then could not be used as a diagnostic for detonation, as with the steel. We tried increasing the length of the acceptor propellant from its normal L/D = 2.2 to L/D = 3., this served to allow the reaction front to fade completely to the sound velocity in the material, but no new information was gained.

Any newly recommended variation in the SLSGT for determining a 1.1 or a 1.3 propellant classification requires that the presently adopted standards be relaxed. If they were relaxed, then the use of PVC for confinement with ½ the amount of donor explosive presently used would be recommended along with an acceptor length of 24 inches rather then 16 inches presently used. The diagnostic for 'fail' and 'pass' or 'go' and 'no-go' would be the measured reaction front velocity (with time of arrival pins) in the propellant (ref. 12).

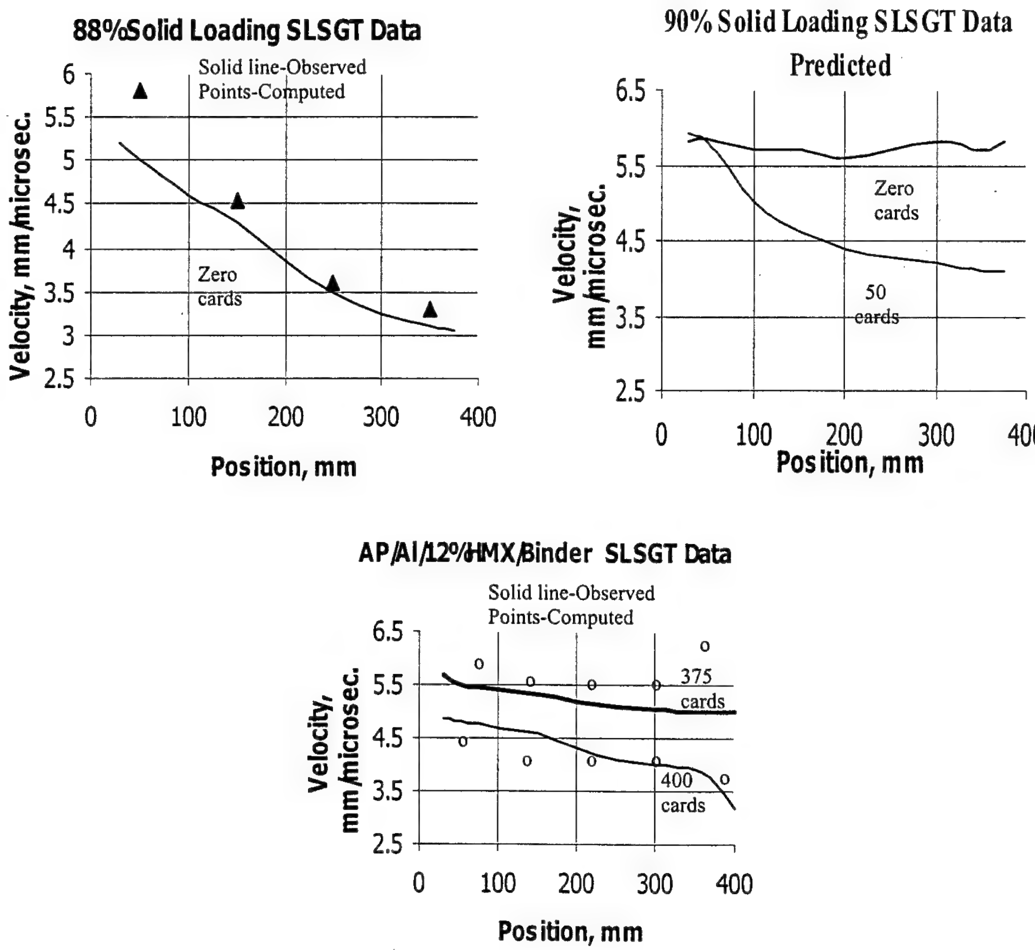


Figure 5. Comparison of computed and observed reaction velocities in the acceptor propellants.

Table 6

Computed Results for NOL-GT (LSGT)

	0 cards (~200 kbar input)	70 cards (~70 kbar input)
Propellant A	Passes (fading reaction)	
Propellant B	Passes (fading reaction)	
Propellant C	Fails	Passes (fading reaction)
Propellant D	Fails	Fails(detonates at ~40kbar)

Computed Results for ELSGT (EIDS)

	0 cards (~200 kbar input)	114 cards (~70 kbar input)
Propellant A	Passes (fading reaction)	
Propellant B	Passes (fading reaction)	
Propellant C	Fails	Passes (fading reaction)
Propellant D	Fails	Fails

Computed Results for SLSGT

	0 cards (~299 kbar input)	375 cards (~70 kbar input)
Propellant A	Passes (fading reaction)	
Propellant B	Fails(borderline)	Passes(~200 kbar)
Propellant C	Fails	fails(~68 kbar)

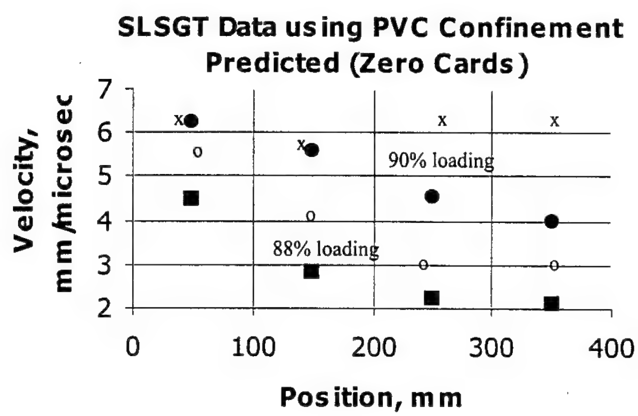


Figure 6. Comparison of reaction velocities with PVC confinement (solid points) and with steel confinement small data points.

CONCLUSIONS

The following conclusions can be reached based on the computer simulations in this paper:

1. Propellant ignition and growth reactive flow models can be used to reproduce observed Gap Tests for 1.3 as well as 1.1 propellants.

2. The model can be a viable tool in designing alternative Gap Test configurations or any other 2-D shock ignition and reaction experiment representing propellant hazard events.

3. This work indicates that 90% solid loading of an AP/Al/binder propellant may be border line in passing the zero cards SLSGT.

4. The use of a shorter length donor and a longer length acceptor with PVC confinement rather then steel may be more realistic for determining the shock sensitivity of propellants.

5. The nitramine containing AP/Al/binder propellants will never pass the zero cards SLSGT and for any of these to be classified as a 1.3 hazard material, new standards will have to be determined.

REFERENCES

1. " Department of Defense Explosives Hazard Classification Procedure" TB 700-2; NAVORD Instruction 8020.8; TO 11A-1-47. 15 October 1959. Latest revision 5 Jan 1998. See also, Bennett, R.R., Schwartz, D.F., Graham, K. J., and Boggs, T.L., "Comments and Position Regarding the Joint Technical Bulletin 'Department of Defense Ammunition and Explosives Hazard Classification Procedures' TB 700-2, dated 5 January 1998." Proceedings of this 2000 DDESB Symposium.

2. Bernecker, R.R. and Hudson, L.C., "Numerical Calibration of Donors for Some NAWSWC Gap Tests", NAWSWC TR 91-236, 1991.

3. Glenn, J.G., "Super Large Scale Gap Test Calibration", TM 91-59, Wright Laboratory Armament Directorate, Eglin AFB, FL, 1991.

4. Cowperthwaite, M. and Zwisler, W., Stanford Research Institute Report, SRI Publication No. Z106, 1973.

5. Miller, P.J. and Lindfors, A.J., "Shock Loading and Reactive Flow Modeling Studies of Void Induced AP/Al/HTPB Propellants", *in Shock-Compression of Condensed Matter, 1997,* AIP publication, CP429.

6. Miller, P.J., Lindfors, A.J. and Pockrandt, S., "Low Pressure Shock Initiation Investigations of 1.3 Propellants", JANNAF 18th PSHS Meeting, CPIA Publication 690, Vol. 1, 1999.

7. Tarver, C.M., Urtiew, P..A. and Tao, W.C., "Shock Initiation of a Heated Ammonium Perchorlate-Based Propellant", *COMBUSTION AND FLAME* 105:123-131 (1996).

8. Tarver, C.M. and Green, L.G., "Using Small Scale Tests to Estimate the Failure Diameter of a Propellant", in *Ninth Symposium (International) on Detonation, 1989, Portland, Oregon.*

9. Sandstrom, F. W., Persson, P., and Olinger, B., "Shock Compression of AP and AN", *in Shock Compression of Condensed Matter, 1993*, Colorado Springs, CO, AIP *Press.*

10. Vittitow, P.S., "Super Large Scale Gap Tests", ", JANNAF 18th PSHS Meeting, CPIA Publication 690, Vol. 1, 1999.

11. "PAC-3 (ERINT) Small-Scale Tests: Super Large Scale Gap Tests", ARC TR-PL-13784, 1995.

12. Graham, K.J., Wesson, J.S., "Shock Sensitivity of Composite Rocket Propellants as Measured in the Super Large-scale Gap Test", *Proceedings of the 1995 JANNAF Propulsion Meeting, Tampa, FL 4-8 Dec 1*995, CPIA Publication 630, Vol. 3, pp 265-276.

13. Wesson, J.S., "Sensitivity Testing of Booster and Sustainer Propellants for Patriot Missile Program", WL-TR 95-7036, Wright Laboratory Armament Directorate, Eglin AFB, 1995.

APPENDIX B

Motor Explosive Hazard Classification Test Program for Storage and Transportation

Claude Merrill

Air Force Research Laboratory Propulsion Directorate, Edwards AFB, CA

ABSTRACT

The latest version of the regulation followed by U.S. military for explosive hazard classification, TB 700-2, has posed difficult issues for large rocket motors with alternate tests for acceptance into explosive Class 1.3. New changes in TB 700-2 can put large rocket motors that formerly would have been in explosive Class 1.3 hazard classification into Classes 1.1 or 1.2 if the alternate tests are used. Rather than using lack of detonation in card gap tests in steel pipe at internal diameters of 37, 73, and 178 mm (1.44, 2.875, and 7.0 inch) at zero cards, the proposed test program plans to verify that use of sub-scale external fire tests (cookoff tests) is valid for obtaining an explosive hazard classification of 1.3 for large rocket motors. This will be accomplished by conducting sub-scale motor exposures to heating by external fire until internal propellant reaction and recording violence of the process. Sixteen sub-scale motors of about 300 mm (12 inch) diameter will be tested with variations in case material, propellant, and fire heating methods. Two propellants having Naval Ordnance Laboratory (NOL) card gap values of zero and of 60 to 70 cards will be utilized. Following sub-scale motor testing a much larger motor containing at least 16 times or more zero card propellant weight contained in some of the sub-scale motors will be cookoff tested to demonstrate that the character of response to external fire is the same despite rocket size differences.

BACKGROUND

The regulation followed in the United States for explosive hazard classification, TB 700-2, has had recent changes in an effort to bring alignment with United Nations rules about explosive hazard classification. A number of new, very conservative limitations have been placed on explosive Class 1.3 classification. For the rocket propulsion community very substantial costs will be incurred in complying with the new explosive hazard classification rules for Class 1.3 versus those required for explosive Classes 1.1 and 1.2. Implementation of the new rules may diminish speed of response and effectiveness of our military forces should they get into conflicts. More conservative limitations likely arose from lack of sure knowledge about storage and transportation hazards of rocket motors containing propellant having detonation initiation characteristics near the dividing line between Class 1.1 and Class 1.3 explosives, e.g., 70 cards in the Naval

Ordnance Laboratory (NOL) large scale gap test (LSGT). In efforts to raise rocket motor thrust performance but maintain the lower cost 1.3 hazard classification formulators have added highly energetic materials to rocket propellants that enhance explosive initiation traits to the region of zero to 70 cards as determined by the NOL LSGT. This plan suggests rocket motor testing that will provide experimental demonstration about storage and transportation hazards of rocket motors filled with propellant exhibiting NOL card gap values in the nominal range of zero to 70 cards.

Those formulating storage and transportation explosive hazard classification rules and tests should take note of the fact that no one since the original formulation of rules for rocket motor explosive hazard classification has been injured by detonation of explosive Class 1.3 rocket motors in storage and transportation environments. From this two questions arise, "Were we just lucky", or "Was the explosive initiation characteristic dividing line between explosive Classes 1.1 and 1.3, e.g., 70 cards in the NOL LSGT, a good and adequately conservative choice". Objectives for the following experimental plan are to validate sub-scale testing for large size rocket motors and to provide experimental answers for the questions above.

For rocket motor hazard classification the TB 700-2 regulation guides us to costly full-scale testing and alternate (explosive tests upon the propellant) tests that use unrealistically arduous explosive testing for entry into explosive hazard Class 1.3. Since explosive sources are not allowed in storage and transportation scenarios, large size explosive stimuli testing (greater than that provided by 70 cards in the NOL card gap test) may not meet needs for Class 1.3, rocket motor, storage and transportation hazard classification. As TB 700-2 clearly recognizes, accidental exposure to external fire is the real threat for rocket motors in storage and transportation. Subscale fire tests are logical for obtaining Class 1.1/1.2 or 1.3 explosive hazard classification at reduced cost compared to full scale testing. In United Nations rules, reflected in the current TB 700-2, more conservative concepts about allowable fragment and firebrand distances from the reacting/deflagrating explosive material have been pushing rocket motors that formerly would have been easily in hazard Class 1.3 into explosive Class 1.2. This is highly disturbing since explosive Class 1.2 items include those that are ultimate hazardous fragment hazards. That is, artillery warheads that throw enormous multitudes of metal fragments in all directions that are easily lethal to distances exceeding 500 meters, and, depending on fragment weights, can send lethal metal fragments well beyond 1000 meters. This was not true for explosive Class 1.3 rocket motors, past or present, that do not project many high density material fragments (typically, less than 10 fragments). Fragment distances are typically less than 200 meters. Often the single, long range, (perhaps, more than 100 meters) material projection from a rocket motor erupting upon exposure to an external fire has been a weather seal out of the rocket motor nozzle. Should rocket motors that project only the weather seal (one fragment) to distances less that 200 meters be relegated to Class 1.2? Burning and non-burning propellant fragments are typically projected from an explosive Class 1.3, case bursting rocket motor stimulated into propellant reaction by an external fire. Propellant fragments are projected a greater distance during fire stimulated motor case bursts as rocket

motors grow larger, perhaps, up to 300 meters or more. Should projection of burning and nonburning propellant fragments at distances less than 300 meters be a reason to put such a rocket motor into explosive Class 1.2? Certainly the lethality of a 1.3 propellant filled rocket motor erupting during exposure to an external fire is orders of magnitude less than for artillery ammunition. Due to higher strength at elevated temperatures, metal cased rocket motors provide longer range propellant projections than for composite cased rocket motors. This leads to the conclusion that tests outcomes adequate for explosive hazard Class 1.3 using steel motor cases would be even milder if the same propellant was tested in a composite cased rocket motor.

Degree of confinement around rocket propellants is an important parameter in the speed and violence of reaction to an external heat source, such as, a fire. Since rocket motors typically operate at elevated pressures, change in reaction rates is clearly shown by combustion bomb or small motor firing studies to determine propellant burn rate variation with increased pressure. Even when so called "slope breaks" (burn rate pressure exponent excursions from less than 0.7 up to less than 1.8) provide elevated pressure burn rate exponents as high as 1.6, no detonations have ever been observed. If the requirement was that explosive Class 1.3 rocket propellants must not exhibit slope breaks under 100 atmospheres pressure (about 10 MPa or about 1500 psi) or less, no detonations would be expected from a burning stimulus even at higher pressures (1, Combustion Roles in Safety of Less Explosively Sensitive Class 1.3 Propellants, Claude Merrill, presented at the Fourth International Symposium of Special Topics in Chemical Propulsion: *Challenges in Propellant and Combustion 100 Years after Nobel,* Industrihuset (House of Industry), Stockholm, Sweden, 27-31 May 1996, published in book, K. K. Kuo, Editor.). External, congested, storage arrangements for rocket motors could never produce confinement as high as 100 atmospheres. Thus, external confinement by close packed goods should not be a concern for explosive Class 1.3 rocket motors.

Solid propellant explosive critical diameters would be expected to decrease only modestly with increasing temperature for propellant grains. This would be expected since solid propellant explosive critical diameters would be expected to have roughly parallel explosive behavior changes with burn rates that exhibit only a weakly increasing burn rate with increasing temperatures. If a solid propellant had a major shift in burn rate pressure exponent to a value above 2 at pressures below about 100 atmospheres pressure, concerns should be raised for increased propensity for detonation. However, if propellant burn rates lack dramatic burn rate increases at normal rocket motor operating pressures, no concerns should be expressed about dramatic increases in ease of transitioning to detonation by heating up explosive Class 1.3 solid propellants up to their spontaneous combustion temperatures.

DISCUSSION

Testing for this plan will be fast cookoff, external fire experiments conducted with sub-scale rocket motor models and with at least one larger rocket motor representative of full-scale size being at least 2.5 times larger in diameter and length than for the sub-scale motors. That is, about 16 times or more amount of solid propellant. Data collection goals for the test program are to determine air shock, fire brand ranges, and fragment ranges for fast cookoff responses of rocket motors filled with solid propellants having card gap values close to 70 cards in the NOL LSGT. In gathering the data certain questions should be answered, such as:

- Does motor size, once above some minimum dimension, reliably provide similar reactive violence during fast cookoff regardless of size, e.g., no detonations?
- Does use of fuel oil or propane fires provide similar experimental outcomes?
- Does fire heating along full or partial motor lengths provide similar experimental outcomes?
- Does time to propellant reaction in a rocket motor during an external fire, fast cookoff event have any significant effect upon the violence of the motor response?
- Do motors containing solid propellant having NOL card gap values near 70 cards provide increased detonation hazard risk in fast cookoff events when motor parts during a case burst event can impact nearby hard structures, e.g., I-beam?
- Will the difference in cookoff responses between motors containing the same propellant but having either steel or composite motor cases require a change in storage and transportation hazard classification?

Overall reactive response in cookoff events would be expected to be quantitatively more violent as motor size increases, but not change in character, e.g., no transition to detonation with more than an order of magnitude increase in propellant volume. Sub-scale motors for this program should have the following characteristics:

- Have an outer diameter of about 0.3 meter (about 12 inches) or larger.
- Have an overall propellant grain length of about 0.4 meter (about 16 inches) or greater.
- Have a center perforated or end burning propellant grain roughly matching that for the full-scale motor. Finocyl or slot configurations will not be required as long as the initial K sub n area ratio (K_n, free propellant grain surface area divided by the gas escape cross sectional area from the motor chamber) condition is matched with that for the full-scale motor.
- Propellant used must not exhibit a dramatic burn rate pressure exponent change at pressures lower than 100 atmospheres pressure.
- Use solid propellant having the same NOL LSGT values as for the full-scale size

motor that the sub-scale motor is representing, e.g., near 70 cards.

- Use solid propellant matching burn rate as a function of pressure as for the full-scale motor.
- The solid propellant will have about the same tensile and strength characteristics as for the full-scale motor.
- Have a propellant web thickness of about 60 millimeters (about 2.5 inches) or greater.

This is based on the finding that 70 card propellants have explosive critical diameters near 25 mm (1-inch).

- Use the same case bonding or inserted cartridge materials as for the full-scale motor.
- Case bonding/insulation system along sides of the propellant grain should be as thick as for the full-scale rocket motor.
- Have forward and aft domes insulated with full-scale motor bonding/insulation materials to a thickness at least twice as great as for the sides of the propellant grain.
- Have motor cases designed to have about the same ambient temperature burst pressure or greater than for the full-scale motor.
- Have an outlet port for combustion gases centrally located in one motor dome.
- Although a nozzle is not required, outlet area for propellant combustion gas escape should have the same initial ratio of propellant grain free surface area divided by outlet area as for the full-scale motor. This ratio is often called K sub n, or K_n.
- Construct 8 sub-scale test motor cases each from steel and composite materials.
- Make all motor cases into rocket motors by adding insulation, propellant, and gas outlet port.
- In 6 composite case motors use marginal zero card propellant as measured by NOL LSGT.
- In 2 composite case motors use 60 to 69 card propellant as measured by NOL LSGT.
- In 6 steel case motors use marginal zero card propellant as measured by NOL LSGT.
- In 2 steel case motors use 60 to 69 card propellant as measured by NOL LSGT.

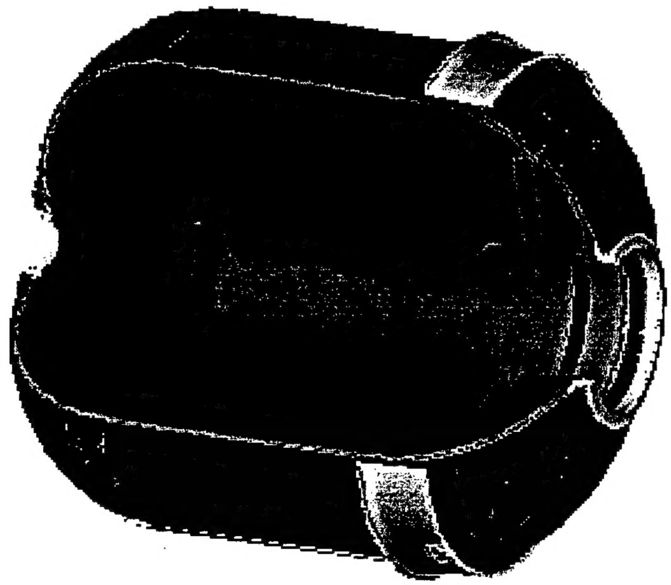


Figure 1. Rough configuration for sub-scale test motor (head end grain not required).

TESTS AND CONFIGURATIONS

All sub-scale motors will be tested suspended by redundant, heavy steel cables so that motors can move laterally more than 15 cm (~6 inches) and lengthwise more than 45 cm (~18 inches). Connections to the motors should provide confidence that motors cannot escape the immediate test area should strong directional thrust be provided once propellant combustion is initiated. Cable length connecting from a secure structure to sub-scale motors will be 1.5 meters (~5 feet) or more. At 15 cm (~6 inches) laterally on both sides will be placed vertical, heavy wall 4" OD steel pipe or 6" I-beam. On forward and aft ends of the sub-scale motors will be placed heavy steel plates having a 15 cm (~6 inches) diameter by 7.5 cm (~3 inches) thick projection located such that the sub-scale test motor forward or aft closure will centrally impact the 15 cm diameter projection should adequate motor thrust be provided upon rocket propellant combustion. Collision of rocket motors or rocket motor parts with steel beams during an external fire cookoff is considered to be the storage and transportation circumstance most likely to provoke detonation for motors containing propellant having NOL card gap values in the range of 70 cards.

Data to be gathered are at least air shock versus distance from the cookoff test motor, 2 videos from different angles, motor structure fragments weights greater than 25 grams and distance from the test center, rough measurement of maximum firebrand distances from video observation, and size and distance of unburned propellant pieces larger than 25 grams weight.

Heat 6 sub-scale composite case motors containing zero card propellant by open fire in the following manner:

a) one motor heated full length with an engulfing liquid fuel fire, e.g., diesel fuel, kerosene, or rough equivalent
b) one motor heated at aft quarter of length with small liquid fuel fire
c) one motor heated at forward quarter of length with small liquid fuel fire
d) one motor heated full length by propane burners spaced 15 cm apart
e) one motor heated at aft quarter of length with propane fire; one or more burners
f) one motor heated at forward quarter of length with propane fire; one or more burners

Heat 6 sub-scale steel case motors containing zero card propellant by open fire in the following manner:

a) one motor heated full length with an engulfing liquid fuel fire, e.g., diesel fuel, kerosene, or rough equivalent
b) one motor heated at aft quarter of length with small liquid fuel fire
c) one motor heated at forward quarter of length with small liquid fuel fire
d) one motor heated full length by propane burners spaced 15 cm apart
e) one motor heated at aft quarter of length with propane fire; one or more burners
f) one motor heated at forward quarter of length with propane fire; one or more burners

Heat 2 sub-scale composite case motors containing 60 to 69 card propellant by open fire in the following manner:

a) one motor heated at aft quarter of length with small liquid fuel fire
b) one motor heated at aft quarter of length with propane fire; one or more burners

Heat 2 sub-scale steel case motors containing 60 to 69 card propellant by open fire in the following manner:

a) one motor heated at aft quarter of length with small liquid fuel fire
b) one motor heated at aft quarter of length with propane fire; one or more burners

A full scale or intermediate size motor consisting of motor case, attached nozzle, insulation and bonding materials and zero card (by NOL LSGT), solid propellant will be tested with a full length fire in such a manner that the motor cannot escape from the test position except in subdivided form. If sub-scale tests do not show any marked preference for source of fire, fuel oil or propane fires can be used. Motor diameter

should be equal to or greater than 0.75 meters (~30 inches) and propellant grain length should be equal to or greater than 1.0 meters (~40 inches). Hard structures for the test motor or its pieces to impact will not be part of the cookoff test. It is desirable that the approximately 0.8 meter diameter be an intermediate size test motor with a substantially larger motor filled with the zero card propellant to be tested subsequently.

SUMMARY

Some people have insisted on having only very smoky, engulfing, liquid fuel fires used for fast cookoff tests. Typical rocket motor cookoff, fuel fire durations are usually in great excess of that needed to cause rocket motors to react. This set of fire conditions provides the maximum heating rates around the test rocket motors. However, external fires in real life can provide various amounts of smoke and high heating rate coverage on any fraction of rocket motor surfaces. This test program is designed to demonstrate that modest variations in heating rates and large differences in smoke content can provide similar energetic responses for explosive Class 1.3 rocket motors treated with external fires. Propane fires have some real advantages for cookoff tests in that test motors can be readily observed until they react. When they do react, clear observations of how the motors react might lead to concepts for making rocket motors safer in external fires. Additionally, propane fires can readily be shut off once a cookoff test specimen has reacted. Use of pools of kerosene like fuels is wasteful since no convenient and tidy means are available for stopping their burning. In some areas using propane fires will reduce problems with local air pollution control authorities.

Concerns have been raised that increasing the energy of solid propellants to the range of zero to 69 cards by the NOL LGST may make them less safe than needed for explosive Class 1.3 rocket motors. Careful adjustment of solid propellant energetics while maintaining explosive card gap values by the NOL LSGT at less that 70 cards has been considered by some observers as "gaming" and somewhat reckless with storage and transportation risks for the rocket motors so produced. This test program was designed to demonstrate whether motors filled with the more detonation sensitive, explosive Class 1.3 propellants are in fact adequately safe for Class 1.3 storage and transportation scenarios. The positioning of sturdy impact structures around the sub-scale test motors was intended as a modest overtest for cookoff events where collision with some building structure might produce propellant breakup and, thus, enhance detonation probabilities. If no detonations occur in the open flame, sub-scale rocket motor, cookoff test program as described above, rocket motors containing 69 card or less propellant should be considered adequately safe for explosive Class 1.3 storage and transportation.

Fixed fragment distance limitations for explosive Class 1.3 rocket motors seems unfair in comparison with past practices. Use of K8 (cube root of energetic material weight in pounds multiplied by 8 to obtain a safe distances) for large, explosive Class 1.3, rocket motors has seemed a good operating method. As rocket

motors get larger and larger so should the standoff distances to other facilities and inhabited buildings. A fixed distance for fragment projections sets up a need for full scale testing since once an otherwise explosive Class 1.3 rocket motor becomes large enough, it is likely to violate the fixed fragment projection limitation. If fragment projection by simple motor case bursting were allowed (orders of magnitude safer than 2 pi projections of metallic fragments from a detonation), rocket motors could logically be assigned the hazard classification of the solid propellant. Adopting solid propellant Class 1.3 explosive hazard classification for rocket motors would require that certain minimum test criteria be met. This would mean passing tests such as the normal thermal stability (48 hours with no distortion, gassing, or color change), drop weight impact (no ignition with 8 lbs dropped 10 inches or equivalent), and NOL large scale card gap tests (less than 70 cards). However, the usual open burning test with 50 mm (2-inch) cubes should be replaced by a series of combustion bomb or small motor test firings to determine propellant burn rate as a function of pressure up to at least 100 atmospheres (~10 MPa or ~1500 psi). Within the pressure range from about 15 atmospheres to 100 atmospheres no excursion of burn rate pressure exponent from values usable in rocket motors (e.g., less than 0.75) to values higher than 0.9 should be observed. The high pressure burning test series demonstrates that should a rocket motor chamber become pressurized through an accidental stimulus, such as, an external fire that no detonations will occur.

This test plan is considered quite flexible during the planning stage. Suggestions for improving the test program for obtaining objectives of providing confidence that explosive Class 1.3 rocket motors nondetonable in storage and transportation conditions and making Class 1.3 hazard classification easier to accomplish are welcome.